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16. Abstracts

This study is a further attempt to find a relationship between daily mortality, air pollution, and weather. New methods were devised for this purpose. The study was comparative; Three U. S. Cities were studied at the same time using the same methods and similar data from each. Due to the insufficient models previously used to study the relationship between mortality and air pollution and weather, a new model was conceptualized. This model, the stimulus-response model, serves as the frame work for extensive analysis of the relationship. The analysis was performed on data from New York City, Philadelphia and Los Angeles. The data included total daily mortality, 65 + mortality, pollutants and weather.

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A COMPARATIVE ANALYSIS OF THE RELATIONSHIP BETWEEN MORTALITY AND AIR POLLUTION AND WEATHER -- II. THE STIMULUS - RESPONSE METHOD OF ANALYSIS AND RESULTS

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This study is a further attempt to find a relationship between daily mortality, air pollution, and weather. New methods were devised for this purpose. The study was comparative; three U.S. cities were studied at the same time using the same methods and similar data from each.

The hypothesis under study was: Can one detect a relationship between mortality and air pollution-weather, using available material on the environment and on mortality? In addition, does this relationship vary by season and city?

Due to the insufficient models previously used to study the relationship between mortality and air pollution and weather, as discussed in my previous paper (A Comparative Analysis of the Relationship ... using Multiple Regression Analysis), a new model was conceptualized. This model, the stimulus-response model, serves as the framework for extensive analysis of the relationship. The analysis was performed on data from New York City, Philadelphia, and Los Angeles. The data included total daily mortality, 65+ mortality, pollutants and weather. The periods covered were: July, 1962-June, 1965 for New York; 1963-4 for Philadelphia; and 1962-5 for Los Angeles. (Further details are also in my previous paper.)

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METHODOLOGY: - Indices represent multivariate variables in which the interaction of each variable is considered. In this study, a specific index of the environment was constructed. The variables shown in previous work to be important in relation to mortality were investigated and an index composed of the more important variables was formed. In the process, different types of abnormal environmental conditions were defined operationally. They were chosen to best represent the specific abnormal environment for each city.

The variables chosen were:

		Winters	Summers
Pollutants -	NYC	SO_2, PM	PM, NO_x, CO
	Phila.	PM, (TSP, COH)	PM, (TSP, COH)
	L.A.	NO_x, CO	NO_x, CO
Weather		Temp.(low)	Temp.(high)
		Relative Humidity	Relative Humidity

New York and Philadelphia have primarily reducing type atmospheres. Inversions occur in winter with high levels of SO_2 and PM. They have stormy weather which could effect mortality and they may have photo-oxidant type conditions in summer. Los Angeles has photo-oxidant conditions in summer: sunny days with inversions and high levels of NO_x and CO. Los Angeles may have both types of atmospheres in winters. Since this index is a "relative" index of abnormal environment, the findings for each city with the use of its own index will be comparable between seasons.

For each day, within each city, the transformed (standard score) values of the original variables are averaged. (The temperature sign is reversed

in winters.) The average for that day is the index value for that day. The index thus becomes a new daily variable.

To indicate on which days abnormal environmental conditions existed, the values of each of the variables involved were examined. If any of the given variables exceeds a score of 1.00 (i.e., one or more standard deviations above its seasonal mean), that day is considered one of abnormal environment. (For temperature in winter, it must be -1.00 or less.) The types of abnormal environment are then specified as follows:

	Pollutants (AP) (one or more)	Temp (T)	Relative Humidity (H)
Type 1	yes ($\geq$ 1 s.d.)	yes	yes
2	yes	yes	no
3	yes	no	yes
4	yes	no	no
5	no	yes	yes

Some analyses will be conducted by type of abnormal environment. The pollutants are the key elements, as they are the major factors under study. Type 5 describes heat waves in summers or either storm weather or freezing spells in winters, in which both temperature and relative humidity need to be extreme. A day of abnormal environment and its index value represent one day in an environmental episode (stimulus).

An empirical index derived from a form of multivariate analysis (such as Multiple Regression analysis, Linear Discriminant Function analysis or Principal Components analysis) on previous data from each city or the data from a different city could be used if one could escape the potential circularity of using such an index.

Mortality in the 65+ age group proved the more sensitive and has been used currently with this model. It is more sensitive because: it has more variation than other age groups; it is much more homogeneous in respect to causes-of-death and these are more likely to be environment related; it contains what is believed to be a more sensitive population.

Days of abnormal environment, and days of excess mortality were examined over time. Contiguous days of abnormal environment and contiguous days of excess mortality were sought. The distributions of intervals between contiguous days was also examined for all indices and their sub-sets (types).

It was found upon examination that individual days of abnormal environment were often contiguous. A majority (60% or more) were within four days of other such days. Days of similar types of abnormal environment tended to be clustered (74-90%). Episodes are the blocks of contiguous days of abnormal environment and are called stimuli. The lengths of the stimuli were then examined to determine the criterion of separation of stimuli.

The lengths of intervals between stimuli and between responses tend to be either very short or very long. This indicates that there are periods with many events and periods with no stimulus or response.

The stimuli and responses (65+ mortality) were examined over time. Calculations of the relationship between the stimulus and response were then made. These were a series of analyses, using different measurements of S&R and different techniques. The response was defined as associated with a given stimulus if it started within the specific time period from the start of the stimulus until one or three days after the end of the stimulus.

RESULTS: Various types of association of stimuli and responses were studied. The first type of association sought was the frequency of individual days with both an abnormal environment and an excess mortality. It was shown to be significantly greater than was expected on the basis of their independent frequencies (see Table 1). The second type sought was the frequency of responses which were associated with stimuli (i.e., S-R pairs; see Table 1).

The rule for such association is described above. This observed frequency of pairing was compared to the frequency expected if one assumed that the responses were distributed in time independent of the distribution of stimuli. The actual calculations can be found in Tables 2 and 3 . When pairing is examined on the basis of the distribution of S and R prior to actual pairing and post pairing, the observed frequency of associations is found to be significant for New York and for Los Angeles(of borderline significance for post pairing)for both lag one and lag three. This analysis does include a consideration of stimulus length. Because of the short period covered for Philadelphia, the number of pairs observed and expected were small and thus might not be sufficient for critical analysis.

The proportion of S or R actually in association varies with the lag used (see Table 1). Allowing the response to begin up to one day after the end of the stimulus only produced pairing in 37-50% of the stimuli and 44-63% of the responses. When the lag was increased to three days, 50-60% of the stimuli were associated with responses and 57-73% of the responses were associated with stimuli.

There also was a definite association between the S & R by the duration of each: the longer the stimulus or response, the more likely that it would be associated with a response or stimulus respectively. There was a direct relationship between the lengths of the associated stimuli and responses. Therefore, when the proportions of days of stimulus or days of response in association are examined, higher proportions are found than when examining episodes in

association. For three days of lag, the proportion of stimulus days that were in S-R pairs is between 61-72% and the proportion of response days in S-R pairs is between 52-77% (see Table 1). So far, the frequencies and durations have been considered. The magnitudes of the S & R have yet to be considered.

The associations of stimuli and responses were not appreciably changed when analysis of the relation was based on start of the stimulus (plus one or three day lag) rather than end plus lag. The start of the responses were almost always on the day or the day after the start of the stimuli. When analysis was performed for the remaining age groups (total - 65+ = <65), few responses were seen and no association was found.

Analysis also was made of the average daily (raw) mortality in relation to stimuli to see if the stimuli produced an average mortality above the normal level (for that season). This analysis includes the many situations where there was a stimulus but no abnormal response. The excess of stimuli probably is due to the multiple cause - multiple effect situation under study (previously discussed). The hypothesis here is that an environmental stimulus would increase mortality to above normal (average) level.

In general, average mortality increased somewhat during the stimulus, reached a modal value, then decreased through the rest of the stimulus and the lag period. Overall, the daily average during the lag period was less than that during the stimuli. These increases and decreases are not remarkably large in the cumulative numbers and are generally in smooth increments of one-two daily deaths. (The smoothness is not only in the large stimuli responses where an increasing number of days are averaged as the period covered increases). The variation in the daily averages, however, is large for both seasons in all three cities. Almost all of the average mortality

for stimulus-related days are above the average daily mortality for a specific season and city for all lengths of stimuli. The exceptions occur more frequently in Philadelphia (especially in the combined summers). Cumulative average daily mortality figures exceed the mean plus one standard deviation level (by season) only for a few of the stimuli lengths in New York and Philadelphia. The average mortality does not appreciably increase by increasing only the lengths of the stimuli. There is some increase in both the average and cumulative average daily mortality associated with increased values of the stimuli. This is more evident in the cumulative averages.

One can conclude that the environmental stimuli are generally followed by average daily mortality which is greater than the daily seasonal mortality. The increases in daily mortality sometimes exceed a level of one standard deviation above the mean.

Table 1

The Frequency of the Associations* of Stimuli and Responses (65+) Using Lags of 1 & 3 Days on S by City

	New York		Phila.		L.A.	
Lag	1 day	3 days	1 day	3 days	1 day	3 days
Stimuli-Response Pairs	40	44	24	30	53	60
Stimuli without Responses	67	56	46	36	58	46
Responses without Stimuli	27	20	35	27	66	49
#S in S-R pairs	45	56	27	37	58	70
#R in S-R pairs	46	53	28	36	62	79
Total # S (original)†	112	112	73	73	116	116
Total # R (original)†	73	73	63	63	128	128
% S in S-R pairs	40.2	50.0	37.0	50.1	50.0	60.3
% R in S-R pairs	63.0	72.6	44.4	57.1	48.4	61.7
# days of S in S-R pairs		176		113		292
# days of R in S-R pairs		143		79		139
Total # S days		278		184		406
Total # R days		186		118		269
% days S in S-R pair		63.3		61.4		71.9
% days R in S-R pair		76.9		66.9		51.7
#S's combined for one R*	5	12	3	7	5	10
as % of total # S's	4.5	10.7	4.1	9.6	4.2	8.5
#R's combined for one S*	6	9	4	6	9	19
or % of total # R's	8.2	12.3	6.3	9.5	7.0	14.8
Strict concordance:						
% of total time = S		28.2		26.3		27.9
% of total time = R		18.8		16.8		18.5
pr.(S&R together on any given day) = pr. (S).pr.(R)		.053		.044		.051
Expected # days of S&R together		52		31		75
Observed # days of S&R together (no lag)		90		47		99
Diff. (O-E)		38		16		24
Significance (X_1^2)		(27.8) p<.01		(8.34) p<.01		(7.80) p<.01

† Excluding responses occurring when S state is unknown (NY & Phila.) or S's when R state unknown (LA).

* R↔S if R starts between first day of S & end of Lag on S; if more than one R so associated, $R = R_1 + R_2$; if second S imbedded in R, $S = S_1 + S_2$.

Table 2

Comparison of Number of Observed S-R Pairs with Expected Numbers of S-R Pairs Based on Daily Probabilities of R & the Distribution in Time of S's by City by Lag for 65+ Mortality (Likelihood of Pairing of Individual S&R) Prior to Pairing*

City-Lag	# Days in Period	# R Onsets	P(R onset) for Ea.Day	Days of S+ Lag	# Expected S-R pairs	# Observed (R's in) S-R pairs	χ^2_1	p
New York	987	73	.0739					
1				382	28.2	46	11.2	p<.001
3				540	39.9	53		p<.05
Philadelphia	700	63	.0900					
1				253	22.8	28	1.2	p>.10
3				363	32.7	36	0.3	p>.10
Los Angeles	1460	128	.0877					
1				523	45.9	62	5.6	p<.02
3				705	61.8	79	4.8	p<.05

* The probability of R's starting during S's (and therefore being paired) is independent of the S's prior to pairing under the null hypothesis (randomness of R's onsets) and the probability of association is therefore the product of the probability of R's starting on any day (assumed uniform) and the number of days covered by the S's with these Lags. This gives the expected number of R's associated with S's if the two were indeed independent (and therefore R's starts as random with regard to the S's (the Ho). The days of S's in which R's can start, to be associated with the S's, is the number of days of S plus the number of lag days minus number of days of 2 day intervals between S's (for 3 day lag case since already accounted for by the Lag) - # expected S's (days) lost by being imbedded in ongoing R's (since these S's no longer represent days in which R can start and thus accounting in part for the durations of R's).

Table 3

Comparison of Number of Observed S-R Pairs with Expected Numbers of S-R Pairs Based on Daily Probabilities of R & the Distribution in Time of S's by City by Lag for 65+ Mortality (Likelihood of Pairing of Individual S&R) Post Pairing*

	# Days in Period	# R Onsets	P(R onset) for ea. day	Days of S + lag**	#Expected S-R pains	#Observed S-R pains	χ^2_1	P
City-Lag								
New York	987							
1		67	.0678	374	25.4	40	8.4	p<.005
3		64	.0648	486	31.5	44	5.0	p=.025
Philadelphia	700							
1		59	.0842	249	21.0	24	0.4	p>.10
3		57	.0814	341	27.8	30	0.2	p>.10
Los Angeles	1460							
1		119	.0815	508	41.4	53	3.3	.05<p<.10
3		109	.0746	652	48.6	60	2.7	p = .10

* The difference between post and prior T18, is that in this one uses number of S&R and S-R pairs found post pairing (i.e., after combinations of S's and R's), compatible with Table 16, and excludes R or S when respective S or R is unknown.

** Now excludes known S's combined rather than expected number
NY: 1 day lag: 5 for 11 days; 3 day lag: 12 for 32 days
Phila: 1 day lag: 3 for 5 days; 3 day lag: 7 for 12 days
LA: 1 day lag: 5 for 9 days; 3 day lag: 10 for 22 days

The Relationships Between the Stimulus and Response Variables

The stimulus variable is the values of the stimulus episodes (stimuli). The value of a stimulus episode is the sum of its daily values. A daily value is the value of the environmental index for that day. Similarly, the response variable is derived from the standard scores for the 65+ mortality. In statistical notation: $S = \{s_i\}$, $s_i = \Sigma_j s_{ij}$; $R = \{r_i\}$, $r_i = \Sigma_j r_{ij}$; i stands for each episode, j stands for each day of each episode.

Using the rules described previously, the associations of stimuli with responses were examined for each city. This yielded for each city a set of stimuli-response pairs, a set of stimuli without responses and a set of responses without stimuli. The description of these various stimuli and responses is provided in Tables 4 and 5. For each city, for winters combined and for summers combined, the means, standard deviations, and the high and low S or R values are provided.

The variations in values (the standard deviations) are large. Large standard deviations in this data are often due to some very large responses, outliers, and the small number of observations from which they were derived.

Mean values of stimuli for summers consistently exceeded those for winters but, except for New York stimuli with paired responses, the differences are not significant *(Table 4). The mean values of responses did not vary consistently with season and differences observed also were not

* t - test

significant*(Table 5). These statements are true for stimuli whether paired or not and responses whether paired or not. The three cities had different mean stimuli values and response values by season. The mean values for the total periods (averages of summers and winters) were not significantly different* for the three cities. This was true for stimuli whether paired or not and responses whether paired or not (Tables 4 and 5).

The mean values of stimuli without responses is significantly higher* than the mean values of stimuli without responses for all three cities (Table 4). The mean values of responses associated with stimuli are consistently higher than the mean values of responses not associated with stimuli in all three cities and, for New York and Los Angeles, the differences are significant*(Table 5). By season, similar but smaller differences occurred. Philadelphia's responses with stimuli were higher than those without, but the small number of cases and large variations in values contributed to the lack of significant findings in that city. Generally, the larger stimuli and responses (in duration and magnitude) were associated with one another.

For each city, the mean daily values and mean total values of the responses associated with stimuli of specified types or all types can be compared with those not associated with stimuli (Table 6). The average daily values of responses which were associated with stimuli were significantly higher* than the average daily values of responses not associated with stimuli for New York and Los Angeles. However, this was not found in Philadelphia. While Philadelphia had proportionately more responses, and larger ones, with no associations than did New York or Los Angeles, there was a trend of increasing mean daily values of responses, and mean response values, with increasingly "bad" weather. An episode is more severe ("bad")

*t - test

when it has more variables that have abnormal values, when it is longer and when it is more complex (composed of more types of daily abnormal environment). Thus, mixed pollution-weather stimuli (1/2-4/5) were longer and greater in magnitude than were mixed pollution-type stimuli (2/3/4), which in turn were worse than just pollution-type stimuli (4), the values for which were consistently lower than those for unpaired responses. (One exception was that L.A.'s mean daily value for type 1/2-4/5 was lower than for type 2/3/4, but the mean total response value did show the noted increase. As the environment became worse the associated responses were longer but had a smaller daily average magnitude in this case.)

This method permits examination of the relationships between the values (i.e., durations and magnitudes) of the stimuli and the responses that have been associated. This is the culmination of the analysis. Using regressions and non-parametric analyses of variance (K-W) this was examined, for each city. In the regressions (Table 7), there was a significant relationship between stimuli and response values in the winters in New York and Philadelphia and in the summers in New York and Los Angeles. When seasons were combined, the correlations were significant in New York City and Los Angeles for S-R pairs and in all 3 cities for total S&R. The values of the stimuli which have no associated responses, and of the responses which have no associated stimuli, are small and therefore do not detract from the relationships (Table 7). In fact, they are close to zero, and the regression lines are therefore weighted at the low end and thus slightly improved. Philadelphia, for both seasons, now has a significant relationship between stimulus and response values when these non-paired S and R are added. Note that these regression results were stronger than those of average mortality and stimuli.

The amount of variation in the response values explained in the regressions by the stimulus values is never more than 29%. This is in part due to the small number of observations in each regression.

The analysis of the relationship between associated stimulus and response values was also performed using a non-parametric analysis of variance (K-W one-factor). The relationship was again found positive and significant. Using this technique the sizes of the responses were significantly greater when the responses were associated with stimuli than when they were not.

In conclusion, one can say that multiple analyses has shown a definite, significant relationship between stimuli and responses. This has been true at each step of the analysis and for each different method used.

The positive results above validate the usefulness of the S-R method. (The S-R model as a statistical model will be derived in the future). The S-R method is a more sensitive analytic technique than any previously used. It incorporates much more information than do other methods. It can be used in a step-wise fashion for seeking association between phenomena related in time and is unique in its ability to study such phenomena. It focuses on the problem and permits in-depth analysis. At present, it utilizes various statistical techniques for testing hypotheses, and it has proven to be flexible.

Table 4

Stimulus Values for Stimuli* Paired and Not Paired
With Responses By City By Season

	Total			Stimuli With Responses			Stimuli Without Responses		
	$\overline{X}_t$	S_t	N_t*	$\overline{X}_s$	S_r	N_r*	$\overline{X}_{\bar{r}}$	$S_{\bar{r}}$	$N^*_{\bar{r}}$
New York									
Winter	1.51	1.68	41	1.66	1.42	19	1.38	1.93	22
Summer	1.80	1.97	59	2.82	1.96	25	1.05	1.68	34
Total	1.68	1.85	100	2.32	1.79	44	1.18	1.76	56
Philadelphia									
Winter	1.74	1.89	33	2.46	1.89	18	0.88	1.62	15
Summer	1.81	1.95	33	2.48	1.93	12	1.43	1.96	21
Total	1.78	1.89	66	2.47	1.72	30	1.20	1.81	36
Los Angeles									
Winter	1.49	1.83	48	2.01	1.82	28	0.76	1.66	20
Summer	2.04	2.76	58	2.79	2.76	32	1.12	2.64	26
Total	1.79	2.41	106	2.43	2.36	60	0.96	2.25	46

* Episodes

Table 5

Response Values for Responses (age 65+) Paired and Not Paired
With Stimuli By City By Season

	Total			Responses With Stimuli			Responses Without Stimuli		
	$\bar{X}_t$	S^D_t	N_t*	$\bar{X}_s$	S^D_s	N_s*	$\bar{X}_{\bar{s}}$	$S^D_{\bar{s}}$	$N^*_{\bar{s}}$
New York									
Winter	4.56	6.75	31	5.57	7.62	19	2.51	2.64	12
Summer	3.91	4.77	33	4.69	5.29	25	1.49	0.42	8
Total	4.23	5.75	64	4.63	5.45	44	2.10	2.07	20
Philadelphia									
Winter	3.19	2.27	32	3.28	2.44	18	2.44	2.26	14
Summer	3.07	5.49	25	3.86	7.94	12	2.39	2.09	13
Total	3.14	3.91	57	3.59	5.15	30	2.42	2.09	27
Los Angeles									
Winter	3.43	2.68	52	3.92	2.57	28	2.87	2.83	24
Summer	3.31	3.82	57	4.27	4.66	32	2.25	2.16	25
Total	3.37	3.32	109	4.05	3.80	60	2.55	2.47	49

* Episodes

Table 6

Mean Daily Values and Mean Total Values
of Response (age 65+) by Type of Associated Stimulus
by City

	Type* of Associated Stimuli				
	No S (0)	All S (1-5)	AP only (4)	AP,T or H/Combo (2/3,4)	(1,5,1/2-4/5)
City					
New York					
Mean daily value	1.312	1.484	1.234	1.475	1.587
Std. Dev.	0.388	0.554	0.408	0.466	0.719
n	32	154	21	75	58
Philadelphia					
Mean daily value	1.611	1.417	1.058	1.138	1.942
Std. Dev.	0.315	0.694	0.552	0.401	0.823
n	42	76	16	32	28
Los Angeles					
Mean daily value	1.249	1.452	1.228	1.780	1.364
Std. Dev.	0.419	0.554	0.404	0.590	0.592
n	102	162	60	54	48
Mean Total Values					
New York	2.10	4.63	1.99	5.03	9.20
Philadelphia	2.42	3.59	1.54	3.31	6.80
Los Angeles	2.55	4.06	3.20	4.37	4.44

* AP = air pollution, T = temperature, H = humidity
Combo = Combination of types

TABLE 7

The Regressions* of Responses (65+ mortality) on Stimuli by City by Season for S-R Pairs and for all S&R with Regression Line Slopes and the Correlation Coefficients

	Mean of Responses (X100)	Slope	Mean of Stimuli (X100)	Correlation Coefficient	Sr.s† (X100)	p**	n
New York							
Winter:							
S-R Pairs	556.85	1.55	165.80	.344	746.28	.10 < p < .05	19
Total S&R	239.73	1.12	104.76	.297	500.10	p < .01	53
Summer:							
S-R Pairs	468.84	0.96	282.32	.463	470.87	p < .01	25
Total S&R	189.87	1.11	156.03	.559	318.34	p < .005	67
Both Seasons:							
S-R Pairs	462.77	1.02	234.28	.418	501.46	p < .005	44
Total S&R	200.80	1.01	134.87	.441	355.53	p < .0005	120
Philadelphia							
Winter:							
S-R Pairs	328.37	0.57	245.53	.540	199.18	p < .01	18
Total S&R	203.74	0.58	123.15	.441	210.88	p < .05	47
Summers:							
S-R Pairs	386.33	0.37	247.83	.116	818.16	ns	12
Total S&R	173.50	0.26	126.11	.110	436.87	ns	46
Both Seasons:							
S-R Pairs	359.10	0.46	251.97	.204	513.31	ns	30
Total S&R	186.59	0.42	124.50	.215	176.98	p < .025	93
Los Angeles							
Winter:							
S-R Pairs	391.85	-0.23	200.96	-.163	263.02	ns	28
Total S&R	246.17	0.11	98.51	.063	278.25	ns	72
Summers:							
S-R Pairs	426.77	0.72	278.65	.516	404.65	p < .005	32
Total S&R	225.99	9.66	140.91	.466	310.50	p < .0005	83
Both Seasons:							
S-R Pairs	405.31	0.52	238.95	.380	354.20	p < .005	60
Total S&R	235.17	0.50	121.84	.337	299.67	p < .0005	155

* Regression line equation: $y=\bar{y} + b(x-\bar{x})$ where y is responses, b is slope, x is stimuli.

** P_R under Ho: r = 0, P_b under Ho: b = slope = 0, same Ho and test (t_{n-2}).

† Sr.s = std. deviation of the regression line (good deal of clustering at low (x,y) levels and some large outliers)
(linear fit appears valid)